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Green roof benefits, opportunities and challenges – A review

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ABSTRACT

Research on the green roof has been raised expeditiously over the past decade. Green roof have been proposed as the sustainable practice to mitigate the adverse effects of urbanization. This review paper includes the history of the green roof, green roof components and multiple benefits (environmental, social and economical) associated with the green roof technology. This paper also emphasizes how the green roof works in different areas, their performance in reducing the stormwater and energy costs, improving air and ecological performance. The benefits of green roof show that it plays an important role in making cities safe, sustainable and resilient to climate change. Therefore, many countries are giving incentives to the house owners for the application of green roof. However, initial high construction costs, high maintenance costs and roof leakage problems are the main challenges associated with the application of green roofs. These challenges can be overcome with the of new cost effective green roof design that can work more effectively and efficiently in any area. Advanced modification and trends of green roof application are also included in this paper. The paper also highlights the research challenges and research gap of the green roof. At the end, for the better performance of the green roofs, some of the recommendations are also provided.

1. Introduction

Climate change and urbanization are the topics of current interest. In the developed countries, urbanization forecasted to attain approximately 83% in 2030 [1]. Due to the rapid economic growth, urbanization is increasing in many countries which degrade the natural landscape as well as the nearby environment [2,3]. These problems can be solved by applying the green stormwater infrastructure strategies. The introduction of new urban development strategies such as rain gardens, green roofs, green walls and bioretention systems can mitigate the adverse effects of urbanization and improve the environment of an area [4,5]. Green roofs also referred as vegetated roofs [5], cool roofs [6], eco roofs (due to ecological benefits), roof garden or living roofs [7–12]. Green roofs are the basically roofs planted with different kind of vegetation/plants on the top of growth medium (substrate). This concept was designed to encourage the vegetations on the top of building to get multiple social, economical and environmental benefits. A green roof typically consists of several components, including vegetation, substrate, filter layer, drainage material, insulation, root barrier and water proofing membranes [13]. The optimal selection of each component of the green roof is very important to get the best outcomes from the green roofs. Each component is equally important and plays very important role for the better performance of green roof in an area [14]. Due to multiple benefits, green roofs are being implemented in many countries. More research is going on the implementation and performance of green roofs in different regions around the world. Fig. 1 shows the 2016 green roof for excellence awards in buildings.

In recent decades, green roofs proved as the sustainable practices and have gained much popularity around the globe [16]. Research on the green roofs shows numerous social, environmental and economical benefits. Significant evidence shows that green roofs can give multiple benefits, such as stormwater management, reduced urban heat island, increased urban plant, wildlife habitat and roof life, enhance the air and water quality and quality of life, decreased the energy consumptions costs of the building, decreased the noise pollution, procreates the recreational activities and increased the green areas and aesthetic value in urban environments [16–20]. As the result of water quality enhancement, green roofs decrease the burden of the water treatment facilities in an area [10,21–25]. Due to the above benefits many countries started to implement the green roofs in buildings. As the result of this more and more green roofs are established day by day around the globe.

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Fig. 1. Green Roof selected for 2016 Excellence Awards in buildings: green roofs on residential buildings (1,2); institutional buildings (3,4); commercial buildings (5,6), pictures taken from [15].

Green roofs commonly classified into four categories. These are intensive, semi-intensive, single-course extensive and multi-course extensive [26]. Intensive green roofs are categorized on the basis of substrate thickness (> 12 in.), a wide variety of plants/vegetations similar ground-level landscapes, high water holding capacity, high capital and maintenance costs and larger weight. Due to the large soil depth, it has more water holding capacity and the plant selection can be more diverse as small trees and shrubs. This also requires more consideration about the building structure capability to bear large weight. Therefore, this type of roofs requires high maintenance in the form of irrigating, weeding and fertile. Green roofs with 6–12 in. substrate thickness, referred as semi-intensive green roofs. Semi-intensive green roofs contain the moderately substrate thickness and usually contain small plants, small shrubs and grass. These roofs require regular maintenance and high capital costs for the better performance. On the other hand, Single-course extensive roofs are the roofs with substrate thickness 3–4 in. In Single-course extensive roofs, mostly sedum uses as the vegetation layer and typically not required irrigation. It required little capital and maintenance costs as compared to all other roofs. These roofs usually very light weight and very useful where the building weight restrictions. While multi-course extensive roofs consist of 4–6 in. substrate thickness. This roof type is usually light weight and mostly use in the USA. Of the four types, single and multi-course extensive roofs are most common around the world due to less weight, not require irrigation and less capital and maintenance costs.

1.1. Methodology

This paper reviewed the global literature from different source, i.e peer reviews, research articles, books, case studies, conferences, technical reports, design guidelines, project summaries and group discussions. A search of a number of different keyword for the green roof that includes green roof technology, green roof history, green roof components, green roof benefits, green roof policies, a new combination of green roof for multiple benefits using Open access, Google scholar, different journal and conferences were used to find the useful information. This review is giving an insightful overview of the green roof to the common user to understand the green roof technology. This review also explains the each component of the green roof and their benefits in details. Many studies were reported to show the green roof benefits for stormwater management and improving the environmental performance in the different areas.

This paper gives an overview of green roof technology and shows how they have significantly contributed to the provide multiple benefits (social, environmental and economical) in urban areas. This review paper differs from the previous review works on the green roofs in terms of various aspects. First of all, on the contrary to the previous literature focusing on one specific topic only, the concept of green roof is explored in a holistic way in this review paper. The review initiates with a historical overview of the green roof technology following by theoretical basics and concise explanations. Then, the green roof each component is comprehensively described with their benefits. Green roof each benefit with the life cycle assessment is described in details.

Moreover, the green roof green roof promotional policies of different countries as well as the research gap, challenges and technical difficulties of green roofs also describes in details. In the end, future perspective of green roof also describes to achieve multiple benefits around the globe.

2. Evolution of green roofs

Green roofs at the building rooftop are old techniques. At ancient times people constructed the green roofs on the rooftops as the rooftop gardens for insulating qualities and to reduce the adverse effects of urbanization. One of the most famous ancient green roofs was the Hanging Gardens of Babylon constructed around 500 BCE. Recently, many countries (Sweden, Finland, Iceland, Denmark, Norway, Greenland, Vinland and the Faeroe Islands) people tend to cover their rooftops with sod during the extreme climatic conditions. However, the present green roofs are the more efficient and effective due to the proper design and specifications used.

The modern green roofs started from Germany in the early 1960s when there were energy crises arose. Germans started constructing green roofs to reduce energy consumptions in the buildings. In modern green roofs, Germany is known as the world leader of green roofs, because green roofs on the large scale were being developed, designed and implemented [27]. Fig. 1 explained the history of green roofs during different time interval around the globe. In 1962, a German researcher Reinhard Bornkamm published his work on green roofs. New development of roof gardens was initiated by BDLA at the Deubau trade fair in Essen in 1973. In the early 1980s, green roofs market expanded quickly and many green roofs were constructed in Germany. Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL) published guidelines for constructing green roofs in the German language.

In Germany, more than 10% of the buildings use green roofs practices for multiple benefits. Since the majority of research and studies of green roofs were in Germany, Scandinavia, Germany, and Switzerland and also reported in their own languages other than English, therefore green roof information not readily available internationally [28]. However, after the green roofs applications initiatives, green roofs become popular all around the globe. Nowadays, research and application of on green roofs at the building in Germany are very popular and green roof coverage is increasing by approximately 13.5 million m^2 every year [29]. Guidelines for green roofs were released by association of Standards and Testing Materials (ASTM) in 2005 and 2006, in which the construction of green roofs explained in detail. FLL published d the latest guidelines for the planning, execution and upkeep the green roof sites. In 2009, USEPA report also released in which the construction and benefits of green roofs explained. More research of green roofs guidelines, implementing and maintenance of green roofs was conducted in the USA and shared with other countries for implementing the green roofs. (Fig. 2).

Nowadays, countries like USA, Canada, Singapore, Australia, Japan, China, Hong Kong and South Korea are making a strong initiative to apply the green roofs at the new as well as existing buildings to achieve the multiples benefits. In Toronto Canada, building with the floor area of $\geq 2000\ m^2$ mandate to apply the green roofs on 20–60% of the total roof area [30]. In Japan, all the new construction should use the green roofs. Public buildings larger than $250\ m^2$ and private buildings larger than $1000\ m^2$ must green 20% of the rooftop or pay 2000USD annually [11]. In Portland, USA, 70% of the areas of all new buildings must use green roofs [31]. In Portland, there were approximately 2 acres green roofs in 2005 and also more green roofs committed to build to achieve the multiple sustainable benefits. In China and Hong Kong, governments are encouraged to apply the green roofs as the green practices [32]. In South Korea, the government is encouraging the public, private sector and stakeholders to apply the green roofs to make cities safe, sustainable and resilient to climate change.

Research on the green roofs has been done in several regions of the world. Blank et al. [33] studied the publication on the green roofs publications that indicated that with respect to the publications on green roofs the USA contributed to 34% of total publications, whereas, European and Asian countries contributed 33% and 20% respectively. Recently, more research on the green roofs, including the each country climate and building characteristics for the more efficient performances at different locations. Razzaghmanesh et al. [34] studied various indigenous Australian ground covers and grass species. From the result authors identified that Carpobrotus Rossii tolerated hot and dry conditions of South Australia with 100% survival rate and maximum growth. As most of the research on green roofs vegetations and substrate are from Scandinavian countries and it cannot be applicable in Asian regions [35]. Nowadays, the more research focuses on new, low cost or new innovative design of green roofs that can give multiple benefits practically on a large scale. With these successful implementations of green roofs in the USA and European countries, green roof research gaining more consideration to the rest of the world. The main objectives of this paper are to review the green roof research around the globe and to identify its social, environmental and economic benefits.

3. Green roofs for retrofitting into the developed areas

In developed urban areas, all the natural areas had been converted into hard surfaces (road, buildings etc.). On the ground surface and underground surface, much of the infrastructure (Telecommunication, sewage, gas etc.) already laid. Under these circumstances to apply the green stormwater infrastructure at the optimal place to achieve multiple benefits is a big challenge. In developed cities, roof areas account for about 40–50% of total impermeable surfaces urban areas [36]. Fig. 3 shows the developed urban areas which indicated that roof areas are very important and we can change these areas in the green area (green roof). There are different kinds of roof types used in the world, so first study the roof type and then select the best green roof to achieve the multiple benefits. Moreover, the green roofs can retrofit on these areas and the adverse effects of urbanization can be reduced. This will also help to improve the environment of the areas.

Green roof technology is not only the best management practice for new development, but also feasible solution for the retrofitting of the existing buildings [37–40]. For the retrofitting the green roofs, Wilkinson et al. studied the retrofit green roofs and walls at two different locations. First green roofs at Sydney, Australia, with a timber frame structure and another one in Rio de Janeiro, Brazil, by using block work construction. Authors want to investigate the thermal performance of these two retrofits green roofs. They investigated these two roofs with walls and compared the results with non-vegetated roofs. Both lightweight retrofit roofs show promising results for cooling as compared to non-vegetated roofs. It is also noted that the structure type and its surface colours also affect the performance of green roofs [38]. The timber frame structure used in the Sydney shows more insulation and cooling properties when compared with the block work structure Rio de Janeiro. This is because the timber structures are not the good heat conductors. Green walls are also helpful in thermal comfort the building and it should also use for the multiple benefits. Gagliano et al. investigated the performances of extensive green roofs with and without natural ventilation in Catania, southern Italy [39]. From the results, it is proved that the thermal insulation is very important to improve the inner comfort of the traditional buildings. From the experiments, it is also proved that the non-insulated green roof reduces the out surface temperature about 36 °C, whereas the insulated green roof green roofs reduce up to 54 °C. Insulation of the building is very important to reduce the heat island phenomena in urban areas. This study also suggests that the green roofs are the best solution in new as well as retrofitting into existing areas in a dry mild climate with hot, dry summer and Mediterranean area [39]. Another study from Toronto, Canada also

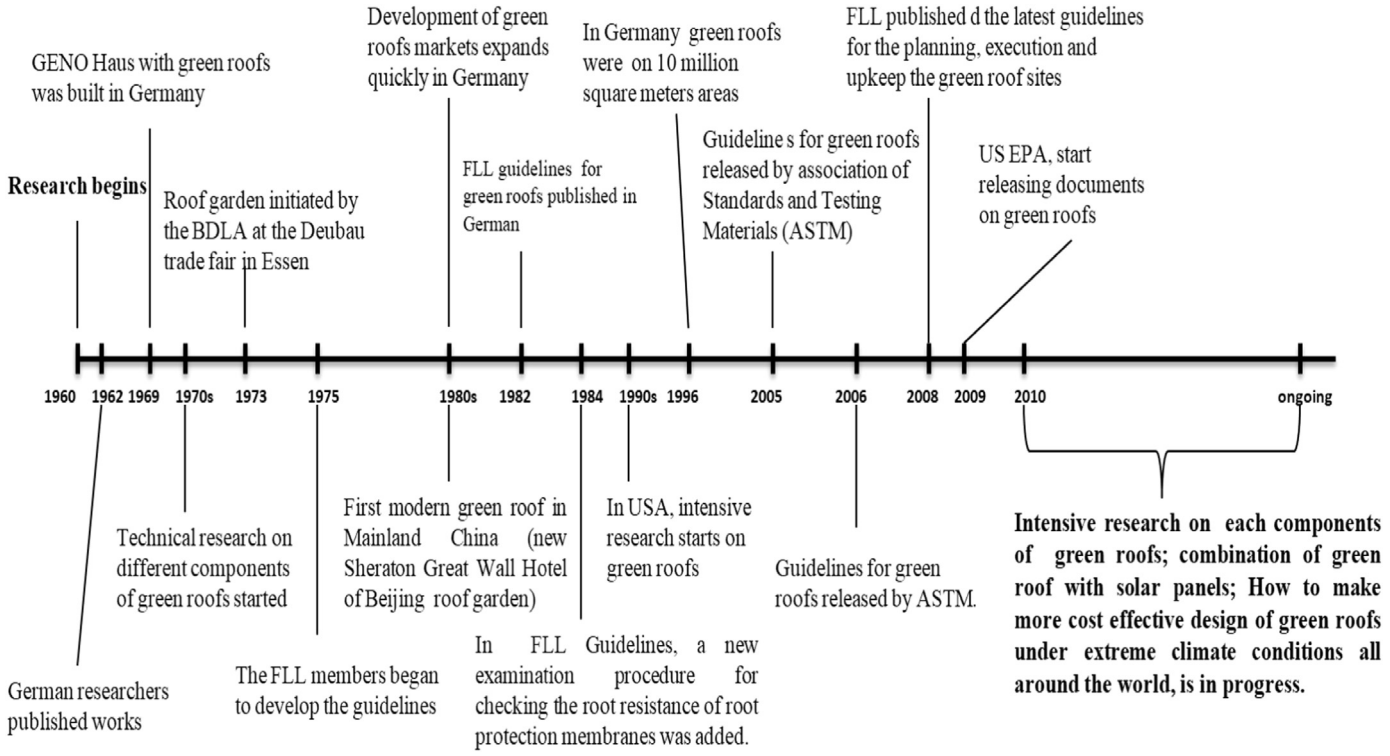

Fig. 2. History of green roofs.

shows that the green roofs retrofit on a building can reduce the surrounding air temperature by up to 0.4 °C during the day and 0.8 °C at night time [39]. Two scientists conducted a research in the Central Business District of Melbourne to evaluate the potential of retrofit roof garden [41]. Research results show that overshadowing of the roof areas and unfavorable orientation were two main barriers, however, about 15% of the Central Business District of Melbourne's buildings were suitable for the green roof retrofit.

In retrofitting green roofs, the main issues that should concern are the increase of additional loads and structural failure. On the other hand, it was recommended that for medium- rise office buildings, which have reinforced concrete slab in the UK, no need additional modification while retrofitting of green roofs [42]. From the study, they concluded that the most of the buildings in the UK can withstand 8–10 kN/m^2 of the dead load which is adequate to green roofs retrofit [42]. Green roofs are suggested as suitable retrofitting technology to improve the insulation for existing buildings [37]. It also argued that the retrofit green roofs into an old building are more cost effective as compared to new buildings [37]. This is because the old buildings are mostly poorly insulated and use a lot of energy annually (for cooling and warming the building). Retrofitting of green roofs can improve the insulation of existing buildings and give multiple economic and environmental benefits. The life span of green roofs is also a very important factor, which is estimated between 40 and 55 years. Acks [43] said the life span of the green roof is 55 years, while Saiz et al. estimated at 50 years [44]. However, Clark et al. [45] prompted it 40 years and Kosareo and Ries [46] estimated green roof life span to be 45 years. This is the very important factor during the life cycle cost assessment.

4. Constituents of green roof structure

Green roofs are structurally designed to mitigate the adverse effect

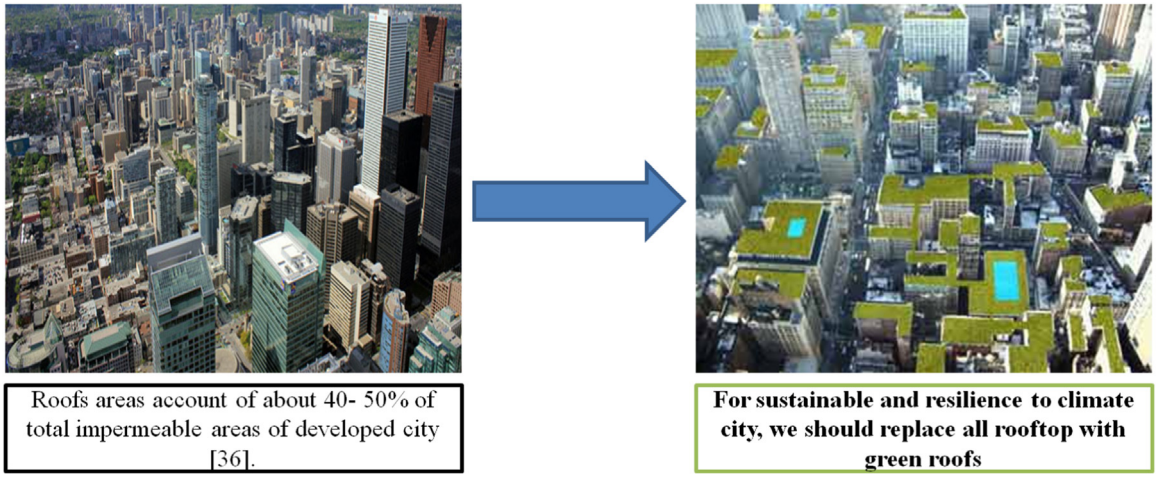

Fig. 3. Retrofit option for applying green roofs in urban areas.

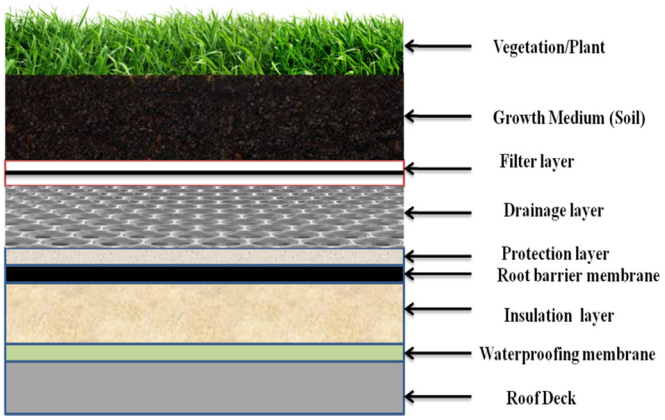

Fig. 4. Typical components of a green roof.

of urbanization. A green roof component varies according to the location and requirements shown in Fig. 4. Typically green roofs comprise following components, i.e; (1) Waterproof membrane and a root barrier membrane, (2) a drainage layer, (3) a filter membrane, (4) growing medium such as soil, and (5) plants. For long term environmental benefits, the selection of each layer according to the location and climatic conditions is very important. Every component of green roofs is very important and should select appropriate to achieve the optimum results.

4.1. Plants/vegetation for maximizing the green roof life

The most vital and interesting part of the development of green roof is the selection of plant layer, which maximize the green roof life. The success of green roofs depends on plant's health. In the selection of plant, we should consider the geographic location, rainfall intensity, humidity, wind and sun exposure. Depth of growth media can also determine the plant species we can use for the green roofs. Many authors worked on the finding of plant species based on the soil depth. Mobasheri [47] explained that the plant species can be used with

Fig. 5. Plants usually use for green roofs all around the globe, modified from [21].

respect to the soil we are using:

- For 0–5 cm soil depth: sedum mosses and lichens.
- For 5–10 cm soil depth: short wildflower meadows, long-growing, drought-tolerance, perennials, grasses, alpines and small bulbs.
- For 10–20 cm soil depth: mixture of low or medium perennials, grasses, bulbs and annuals from dry habitats, wildflowers and hardy sub-shrubs.

Vegetation/Plants of green roofs improve the runoff water quality [21], air quality [48] and reduce the heat waves in an area [49]. However, it should point out that the rooftop is not the natural space for the plant growth [47,50]. Water is always a limiting factor for the rooftop top environments. In addition, building load restrictions limit the soil media depth. The growth media also needs necessary nutrients to maintain the performance of plants. After considering all these restrict conditions on the rooftops, the optimum vegetation/plants for extensive green roofs which can have the following characteristics:

- Ability to withstand drought and extreme climate conditions
- Easily available and cost effective
- No need irrigations regularly
- Short and soft roots
- Have ability to survive under minimal nutrients conditions
- Less maintenance
- More evapotranspiration
- Can reduce heat island phenomena
- Rapid multiplications

It is very difficult that the plants can have all above favorable characteristics explained above, significant progress have been made for the selection of suitable vegetation [48,50,51]. Sedums species are the most popular choice for extensive green roofs around the globe [52], because they can perform well under different climate conditions. Fig. 5 includes the different plants that are used in different countries. Recently, the researchers have been checking the effects of using local plants on green roof performance.

Several studies indicated that the sedum species can have great performance around the globe and can withstand without irrigation for the longer period [48]. Durhman et al. [53] explained that Sedum species survived and maintained active photosynthetic metabolism even after a longer period (4 months) without water, whereas Terri et al. [54] indicated that the Sedum rubrotinctum survived two years without water. Due to these characteristics sedum species used all around the world. Sedum species also proved successful on shallow extensive green roofs and give multiple benefits. Getter and Rowe [55] studied several Sedum species and identified that for sedum species a substrate depth of 7 cm was enough for the growth and performance. A good plant coverage is an important criterion because it protects the green roofs from the winds. Short and soft roots of plants play a meaningful role as it prevents the roots from insertion into roof deck.

As the sedum species is not available all around the world, research should find the suitable local plants for the better performance of green roofs. Blanusa et al. [56] studied to identify the other plant species which can be used alternatively for green roofs. The research result showed that the Stachys byzantine species had more leaf cooling (even in drying substrate, e.g. 5 °C cooler compared with Sedum). However, it is always suitable to apply the local vegetations for green roofs [57,58]. It is because native species already adapted to local climate conditions and easily available etc. Vijayaraghavan and Joshi [59] studied different species to find the most suitable local species for the green roof. From the research, they found that Portulaca grandiflora is also suitable local plant species in tropical wet and dry climate which have uniform characteristics as that of Sedum. Whereas, Schweitzer and Erell [60] investigated four local vegetation species for use in extensive green roofs in different climatic conditions. From the research results, it is identified that Aptenia cordi folia is the best plant species in drought conditions. Monterusso et al. [61] examined eighteen native species in Michigan (USA) for the use in extensive green roofs. However, from the result, it was concluded that only 4 species were able to survive on the non-irrigated extensive green roofs. Sedum species have the ability to enhance the water quality by retaining the different metal ions. Vijayaraghavan et al. [62] performed experiments on vegetated and non-vegetated green roofs to check the performance for metal ion retentions. From the results, it is concluded that the sedum based green roofs have the ability to retain more metal ions. However, more research needed on the selections of local plant species for green roofs, which can enhance the water quality as well as to improve the ecosystem.

4.2. Growth medium for plant growth

This layer can be called the critical layer because it directly affects the plant's growth and the success of a green roof for a long term is associated with this layer. Therefore, the optimum selection of this growth medium (soil) should necessary for the success of a green roof. Most of the green roof benefits are directly correlated with the substrate of green roofs such as water quality enhancement, runoff reduction, peak flow reduction and thermal benefits. The growth medium should have unique properties, i.e. light weight and the high ratio of organic minerals that help for plant growth. However, it is not practical that a substrate can have all desired properties. Therefore, the general practice is to mix the different components in growth substrate. Many authors used commercial substrate, there are few researchers who recommended the other low cost and light weight materials that can be used in the substrate for multiple benefits [63–65].different materials can include in the substrate such as pumice [66], zeolite [67], scoria [68], vermiculite [59], perlite [51], peat [69], crushed brick [70,71] and other low-cost waste materials [72]. Many authors used commercial substrate in green roofs by using local soils, however; these substrates can perform well in those regions. For green roof substrate, it is always recommended to use the local waste material which can make green roof cost effective [73]. On the other hand, the countries where the green roofs are not available commercially, they use the local substrate for the green roof construction. It leads to certain disadvantages such as (1) poor water retention; (2) weight increased that can collapse the structure; (3) promotes the unnecessary local weed growth; (4) washed away the nutrients that are required for the plant growth: (5) can easily become hard [72]. The usage 100% local mix should be avoided because it might promote the local weeds, compact the structure during rain events, cause the structure shrinkage and structural failure.

Green roofs growth media should have a low bulk density because if it has a high bulk density it can collapse the structure. Especially, in old buildings due to load restriction, cannot allow the additional heavy weight substrate. Hence it is always tried to keep the weight of green roof as low as possible. This can be done by adding lower density inorganic material in the substrate. Few researchers also suggested that using the 80% of inorganic materials in green roof growing medium, in this way more weight of the green roofs can reduce [74–76]. Growing media should have the high sorption capacity and less leaching for better performance. Many researchers studied on the leaching tendency of green roof substrate. Organic constitutes in the substrate are recommended essential to provide the nutrient in green roofs. Organic constitutes used in green roof substrate include the mulch [66], peat [73] and some other [73]. On the other hand, some of the research indicated that the organic matter in the green roof substrate affects the runoff water quality of green roof [77]. Therefore, it is recommended to provide the desired quantity of organic matter in the green roof (Growth medium). The German guidelines for the green roofs, Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL) suggests that the green roofs substrate should have organic matter only 4–8% for extensive and 6–12% for intensive green roof type [76].

The green roof substrate should have high water holding capacity (WHC) because it helps to reduce the peak runoff flow and helps to withstand the plants under drought conditions. WHC can be increased by increasing the substrate volume and depth. Few researchers recommend the usage of additive to maximize the water holding capacity of growing media [25]. Cao et al. [68] used biochar in the green roof substrate to improve the water holding capacity. From the result is proved that biochar increased the WHC as well as the plant available water (PAW). FLL recommends WHC > 20% for extensive green roofs which can reduce the peak flow and improve the plant available water [76]. Growing media of green roof should have high air filled porosity (AFP) because it helps the flow of water continuously under rain events and prevents the leakage of a green roof. An optimum substrate should stable and support the wide ranges of the plant/vegetation. It should also light weight and helps plants to withstand under extreme climatic conditions. Growing media of green roof should be designed properly to achieve the multiple benefits for longer periods. An ideal growing media can have the following properties [74]:

- High stability under different conditions
- Locally easily available and support a vast variety of plants
- Cost effective
- Should contain a minimum organic content
- Should have high water holding capacity
- Light weight
- High hydraulic conductivity
- Less leaching and high sorption capacity
- Good aeration and flow properties
- Contribute to enhancing the water quality

It is very difficult that a substrate can have all the above mentioned properties. However, we should select the best substrate with respect to the local conditions. Until now, there is no research have done to evaluate the performance of substrate to the wind erosion, drought conditions and heavy rain events. The effect of compaction due to the light weight of inorganic material over the substrate of the green roof should also be investigated further. More research also needed for the selection of optimal substrate which can have more advantages.

4.3. Filter layer to avoid the clogging in drainage layers

A filter layer of green roofs is used to separate the growth medium from the drainage layer, and preventing smaller particles such as soil fines and plant debris from entering and clogging the drainage layer. This is also called geotextiles, are used to provide better flow for water in the drainage layer [65]. These filter fabrics have high tensile strengths and high water permeability to flow water into the drainage layer. This layer also acts a root barrier membrane for the plants. Wong and Jim [78] investigated the non-woven geotextile filter fabric water retention performance. From the result, it is indicated that this filter media absorbed almost 1.5 L of water/m^2. Moreover, it also increased the water detection capacity of green roofs. The Author investigated that the thicker fabric detained approximately 300% more rainwater that the green roofs without fabrics [79]. Therefore, it is necessary to select the suitable filter fabric to enhance the green roof performance.

4.4. Insulation layer to improve the thermal comfort

An insulation layer is an optional layer on any roof. This layer prevents water stored in the green roof system from extracting heat in the winter or cool air in the summer. More insulation is generally required when green roofs applied on existing roofs in retrofitting projects. Depending on the design and type of roof it should be provided. However, it is provided above the waterproofing, as it further protects the membrane from condensation and physical damage.

4.5. Drainage layer for removal of excess water

The drainage layer is very important for green roofs as it allows the removal of excess water from the substrate. In this way, it reduces the load on the building and chances of a collapse of building structure also minimize. It also protects the waterproof membrane and improves the energy efficiency of the building [80]. There are two commonly major types of drainage layers: (1) Drainage modular panels that are made of (polyethylene or polystyrene) with holes to store more water while draining process. (2) Drainage granular materials have large pore spaces to store more water, i.e. (lightweight expanded clay aggregates (LECA), expanded shale, crushed brick, coarse gravel and stone chips).

Many authors checked the performance of different types of drainage layers in green roofs. Pérez et al. [80] have done experiments to check the thermal behaviour of extensive green roofs in dry Mediterranean Continental climate. He also used rubber crumbs as drainage layer material and checks its performance for energy efficacy. From the result, it is proved that the thermal behaviour of rubber is better than reference roof one. Wong and Jim [78] applied a new drainage layer named as (Nophadrain 5 + 1), which showed that it has the ability to store water up to 4.3 L/m^2. Moreover, drainage layers also can enhance the energy efficacy of building. The biggest challenges for drainage layer are the cost and disposal of drainage layer is a big issue for the drainage layer. Hence, further research needed for the selection of optimal cost effective and environment-friendly drainage layer.

4.6. Waterproofing membrane and root barrier layers

The waterproofing membrane is necessary for the green roof to avoid the leakage of water on the roofs. in the green roof, due to the wet soil and high moisture content increases the chances of leakage of green roofs. Therefore, a waterproofing membrane is very important for green roofs and care should be taken while the selection of waterproofing membranes. These include modified-bitumen sheets, liquid-applied membranes, polymer cement systems single-ply sheet membranes and thermoplastic membranes [31]. Care should be taken while applying the waterproofing membrane and it should also protect from physical and chemical damage. The selection of the optimum waterproofing layer enhances the life of green roofs.

Root barrier is important in intensive green roof type to protect the structure of the green roofs from roots of the plants. If green roofs do not contain this layer then the root can come out from the green roof's structure and disturb the whole green roof structure [81]. The most common root barriers used are thin polyethylene sheets. It is important to check the compatibility of root barrier with the waterproofing membrane and can perform well under different climate conditions.

4.7. General capital cost breakdown of extensive green roof

As an extensive roof is light weight as compared to the intensive roof. The components of the extensive green roof are of light weight and it also contains moderately substrate with usually small plants. Hence, to calculate the typical capital cost breakdown of an extensive green roof is easy as compared to the intensive green roof. Fig. 6 shows the general capital costs breakdown of the extensive green roof [31]. The most important part of the extensive roof is the selection of appropriate soil substrate and drainage layers. Fig. 6 shows that the maximum cost required to prepare mulch (20 mm), soil substrate (100 mm) and drainage (10 mm) is 48% of total cost required for extensive roof. The suitable plant material is also necessary and it requires 31% of the total cost of the extensive roof. Costs require for root barrier and waterproofing membranes are 16% of the total cost. The minimum cost requires for the drip irrigation for the extensive roof that is only 5% of total cost. The capital cost of the extensive green roof is affected by the type of project (new construction or retrofit project), irrigation needs, the slope of the green roof and growing medium depth etc. This is the

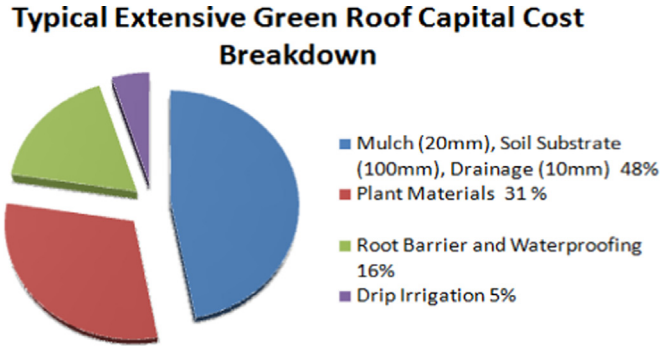

Fig. 6. Shows the general Capital cost breakdown of extensive green roof [31].

general cost capital cost breakdown of the extensive green roof. However, the cost can be minimized if the appropriate local plant and local substrate use for the extensive roof. The cost of the green roofs is the biggest challenge for the application of green roof in an area. Therefore, there is a need to develop cost effective green roofs that can have multiple benefits in the urban area.

5. Benefits of green roofs

5.1. Stormwater retention to reduce peak flow and runoff

Green roofs are the best stormwater management practices in urban areas because the vegetation and substrate layers have abilities to store a large amount of water [36,82]. As a result of this, the chances of flash flooding decrease in urban area. Vegetation/plant increases the evapotranspiration and growing medium absorbs a large amount of rainwater, this causes the reduction in peak flow and runoff. The runoff reduction depends on the many factors which include the type of vegetation, thickness of growing medium, type of drainage material, rainfall intensity and slope of the green roof. The most important part is the substrate of green roof and it should have high moisture holding capacity to store more rainwater. Mickovski et al. [63] compared the 3 different kinds of vegetations (sedum, long and short grass) to check the performance for surface runoff at different rainfall events (Fig. 7). From the results, it is proved that the sedum produced the greater surface runoff volume than other vegetations.

Many authors studied the green roofs hydrological performance at different regions all around the world [83–91]. Fig. 7 shows the water retention (%) from the green roofs ranges from 55% to 88%. Bengtsson [83] studied 3 cm thick sedum-moss roofs for the runoff analysis by using the real and artificial storms events. Results indicated that the green can reduce the runoff and it can be used to control runoff in urban areas. Carter [86] indicated that the green roof runoff retention is more than as compared to the existing roof runoff retention. Moreover, peak outflows also reduce by using the green roof. Zhang et al. [90] examined the stormwater retention capacity by using the green roof in

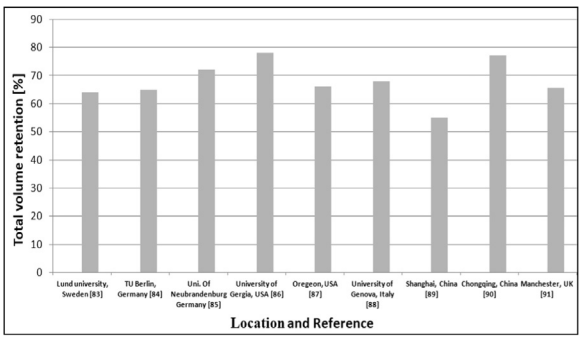

Fig. 7. Show the runoff retention (%) from the green roof.

Chongqing, China. Examining 19 rainfall events, the results indicated that the green roof retained the runoff on an average rate of 77.2%. This indicated that the green roofs are the suitable solution for stormwater management in urban areas. A similar result was found when speak et al. [92] conducted the experiment an aged intensive green roof in Manchester, UK. They analyzed the 69 rainfall events; results indicated that the green roofs retained the runoff 65.7%. Other researchers [83,84,87,89] also noted uniform results for water retention by using the green roofs.

Vegetation of green roof plays an important role in the water retention because every plant has its own water holding and transpiration capacity [92]. Nagas and dunnett [93] studied different plant species to check their relationship with runoff retention. From the results, it is indicated that every plant species have different water retention capacity. However, grasses were the best to hold the more amount of water. Drainage layer and a green roof slope [94–96] also affect the water retention from the green roofs. Liu et al. [97] checked the performance of green roof to control a large amount of rainfall runoff in Deakin University, Australia. From the geographic information system (GIS) analysis, the results manifested that the green roofs are very helpful in mitigating of urban flash floods [97]. For the better performance of green roofs in runoff reduction, there is a need to consider all above factors while designing the green roof.

5.2. Water quality enhancement for water utilization

Green roofs are the best practices for the stormwater runoff control as well to improve the water quality [77,93–97]. Green roof substrate and vegetation layers play an important role in runoff reduction and to absorb the different pollutant from the rainwater. Substrate absorbed the pollutants and heavy metals from the rainwater and enhances the water quality. Berndtsson et al. [95] examined the extensive green roof to check the water quality. From the results, it is proved that the ammonia nitrogen percentage in runoff from the green roof is less as compared percentage in rainwater. Berndtsson [16] reviewed several research articles on green roof water quality performance and revealed that the percentage of the heavy metals in urban runoff from the hard surfaces significantly higher than the runoff from the green roof surfaces. Mostly, the reduction of the concentration of heavy metals depends on the amount of runoff volume reduction. Row [55] also reviewed the articles from different regions and showed that the green roofs have a capability to improve the water quality. Teemusk and Mander [98] performed experiments on extensive green roof performance in Estonia and the result revealed that the green roof reduced the nitrogen as compared to runoff. Therefore, the green roofs are the suitable option to improve the water quality in the urban area.

On the other hand, few of research results show that green roofs degrade the water quality [16,96,99]. Berndtsson [16] study showed that the green roof runoff included heavy metals, such as Cu, Fe, Zn and Al. The results also showed that in the summer months, the extensive roof systems with grass retained a huge amount of heavy metals which include 97% of Cu, 96% of Zn, 92% of Cd, and 99% of Pb respectively. Moran et al. [99] studied the green roof to the check the performance for water quality from the green roof in North Carolina. However, the runoff from the green roof contained a large amount of total nitrogen. Beechamand M. Razzaghmanesh [100] studied 16 green roofs at Adelaide, South Australia to check the performance for water quality and quantity. Results showed that organic material also affects the water quality of green roofs. Moreover, the green roofs with a less organic material in the growing substrate showed more good water quality. The proportions of heavy metals and nitrogen from the green roof runoff depend on the substrate type, the fertilizer used and the age of the green roof [16]. The following factors are very important to enhance the runoff water quality from the green roofs.

- Type of plant

- Type of substrate used in green roof
- Intensity of rain
- Local place (contained pollution sources or not)
- Type of green roof (Intensive or extensive)
- Age of green roof
- Type of drainage layer
- Fertilizers type used
- Organic material used in the substrate

These all above factors play an important role in water quality enhancement of green roofs. However, there is a limited substrate used for the green roofs around the globe. There is a need for more research on the local substrate as well as vegetation that can improve the water quality and quantity.

5.3. Thermal benefits to improve the environment and reduce energy costs

Reduction of surface temperature and thermal comfort are the two important functions of the green roof in urban areas. Green roofs add thermal resistance to the building this causes the cooling of the building in summer and also reduces the energy costs [101–103]. Green roof vegetation and substrate absorbs fewer solar radiations than the other types of roofs, hence also saving the money use for cooling [102]. A study from the Japan revealed that green roofs can reduce the surface temperature from 30 °C TO 60 °C [102]. This helps to save energy that requires for cooling the building. Guo [104] studied the sedum green roofs to investigate the energy efficiency at Guangzhou, China. He used the DeST simulation for the analysis; the results showed annual cooling energy reduction was 3.83%. However, during the in the air-conditioning season for cooling of the whole building decreased by 0.47% and during the conditioning, season is the reduced to 0.83%. A similar effort was made by Zhao and Xue [105] to analyze the power consumption of light weight green roof in Shanghai, China. The result indicated that by using the green roofs power saving at daytime was found around 20.9% and at night the saving was 15.3%. Several studies have discussed the green roofs performance in the urban area for reducing the urban heat island phenomena [101,106–112]. Yang et al. [106] investigated the thermal performance of green roof by proposing two two new indexes named as insulation factor and comprehensive temperature regulation factor. From the results analysis, it is found that insulation factor has a little variation, whereas comprehensive temperature regulation factor has a great variation in different seasons. The results of comprehensive temperature regulation factor indicate that, in Shanghai city, green roof cooling effect is stronger in summer and weakest in winter [106]. Results also concluded that leaf area index, reflectivity of substrate layer and common roof are the mainly responsible for the change in temperature regulation factor value. Another study [107] used co-simulation approach with EnergyPlus and ENVI-met to evaluate the green roof thermal benefits in urban areas. Research results revealed that the green roofs are very helpful in reducing the surface temperature as well as the energy consumption of the building in urban areas. Yeom et al. [109] investigated the cooling potential of a green roof connect to a radiant cooling system in southern California. Experiments demonstrate the performance green roof with a radiant cooling system in cooling the indoor temperature is better than other cells. Thus, this study proved that a green roof is very helpful practices for controlling indoor temperature of the building. Karteris et al. [110] research results revealed that green roof could achieve reduction in heating and cooling consumptions up to 5% and 16% respectively. This will helps to reduce the energy consumption cost of the buildings in urban areas. Research results show that the green performance significantly can be seen in the hottest and driest climates (Fig. 8). Various studies discussed the possible influence of green roofs in urban sustainability by reducing the UHI effect [86–88]. Findings indicate that the highest impact of green roofs occurs in the hottest and driest climates (Fig. 9). Alexandri and Jones [115] show the surface

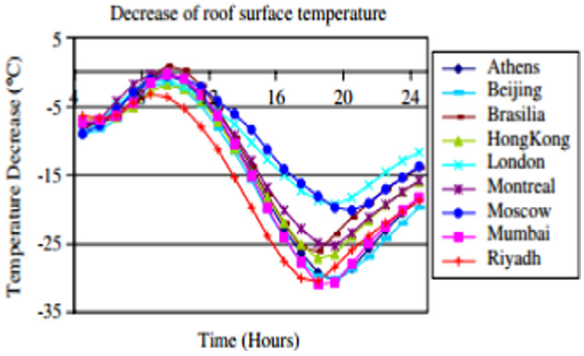

Fig. 8. Extensive green roof's performance for surface temperature reduction in different cities worldwide [113].

temperature reduction at different regions. The result from the hot and dry region shows the maximum reduction of surface temperature from green roofs [113].

In Singapore, Qin et al. [114] measured the surface temperature from green roof and bare roof. When the results were compared with each other, the green roof showed promising results in decreasing the surface temperature as compared to the bare roof (Fig. 9). Green roofs have the ability to decrease the surface temperature and hence improving the environment of an area.

Green roofs are suitable to decrease the surface temperature at cold as well as hot regions. Sun et al. [115] studied green roofs at two different locations; at the Tsinghua University in China and at Princeton University in the U.S to analyze the surface temperature variation. However, the results revealed that the green roofs reduced the surface temperature and heat losses at both sites. To save energy from green roofs depend on many factors, such as the depth and composition of the substrate, the climatic conditions, plant type, type of irrigation, type of green roof and design insulation [103]. These all factors should include enhancing the thermal benefits from the green roofs. It is advised to study different plant types and seasonal variation impact on temperature reduction performance of a green roof at different locations.

5.4. Air cleaning for easy comfort into urban areas

Green roof has ability to capture the harmful fine dust particles from the air that could help to comfort for human in highly developed urban areas. In urban areas, the air usually contained the fine dust particles that make the urban environment bad and discomfort [116]. Green roofs help to pacify the air pollution by two different ways. First, the plants capture the small air pollutants through stomata [117]. Secondly, the green roofs lower the surface temperature which helps in fossils burning to meet energy requirements. Zhang et al. [116] research showed that a 1000 m^2 green roof can capture dust approximately 160–220 kg per year results in improving the environment of an area. A similar research was followed by Hung [49] green roofs in a city town reduced the dust drops to the city by 100 mg/m. Every plant has its own abilities to capture dust. This is because of the different properties of the trees leaves and canopy structure. Deciduous shrub has the maximum capability to absorb more dust particles, whereas the herb has the minimum capability to absorb the dust particles [118]. Trees are dominated to absorb a large amount of air dust particles [119]. A study from Zhengzhou, China shows that the tree species accounts for capturing 87.0% of the dust in the air, shrubs for 11.3%, and lawns for 1.7%. Moreover, it is also proved that the trees can have more ability to air pollutants [120]. Due to the above fact, it can say that the intensive green roofs are better for capturing the air dust particles. However, there is more research needed to check the performance of different green to clean air in urban areas.

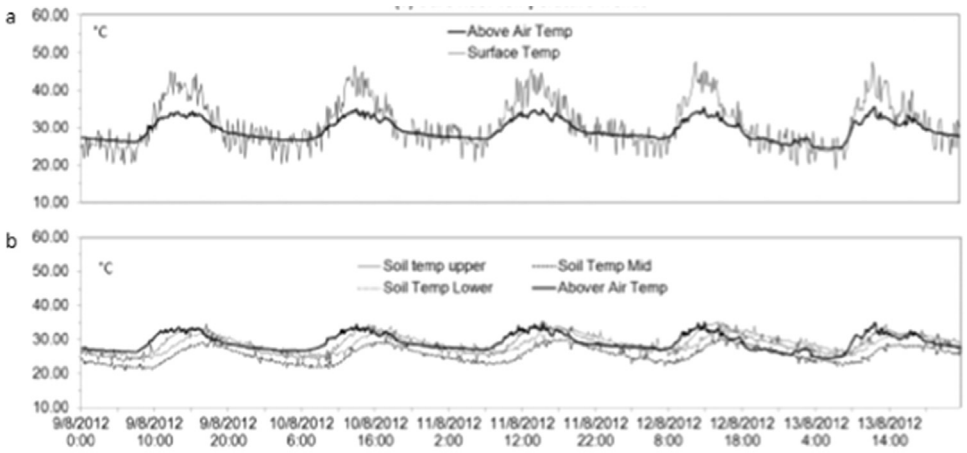

Fig. 9. Shows the surface temperature variations of (a) a bare roof and (b) a green roof in Singapore [114].

5.5. Noise reduction

Another benefit of the green roof is the reduction of the noise level. A green roof can reduce the noise as compared to without green roofs [121–124]. However, a few studies have done to estimate the noise reduction from the green roof. Ni [121] investigated the impact of indoor greening on the reduction of the noise reduction annoyance level and the results indicated that green plants can help to reduce the noise level. Connelly and Hodgson [122] investigated green roofs and non-vegetated roof in the field to check the noise level reduction. From the results, it is proved that vegetated roofs reduced noise frequency by 10 and 20 dB. Green roofs have ability to absorb the sound waves and to reduce the sound level as compared to non-vegetated roof. Yang et al. performed field experiments on green roofs to check the performance of green roof in reducing the noise in urban areas. Results showed that the vegetation has a high coefficient of absorption that helps to reduce the noise [124]. The results also explained that the green roof vegetation layer is very important for the reduction of noise.

5.6. Ecological benefits

Green roofs also enhance the aesthetic of an area as well as the wildlife [18]. Peng and Jim [124] showed that the green roofs play an important role to enhance the urban ecology, however it is difficult to measure in urban areas. Various studies [125,126] showed that the green roofs are very helpful to reduce the habitat loss in urban areas. Green roofs also promote the recreational activities in urban areas. It promotes the wildlife by allowing them to come in green areas. It tries to make impervious surface areas into natural green areas that can also additional environmental benefits in urban areas.

5.7. Social Benefits

Green roofs provide the relief from the concrete construction by introducing the green space in urban areas. Various studies [49,121,127] indicated that the green roofs provide the pleasant effect to the urban inhabitants by reducing the air and noise pollution. Green open spaces attract to eyes and tried to connect people together for roof gardening. Green roofs also enhance the property values [127]. Green roofs can additionally create opportunities for urban agriculture. They can produce the different vegetables and make the society self-resilient for the food production. Whittinghill et al. [128] irrigated Tomatoes, green beans, cucumbers, peppers, basil, and chives for food production from green roofs in Michigan, USA. The results showed that all the plants except pepper produced the enough yield and are very helpful for the food production from green roofs. Moreover, the results also indicated that with proper selection of vegetable type for the food production and proper management in an extensive green roof can be helpful for more food production.

5.8. Economic benefits

Several studies have discussed that the green roofs have multiple cost benefits [129,130]. However, the cost benefits of green roofs determined by various factors such as the selection of green roof system and by the plant's types. Green roof waterproofing layers are also responsible for the green roofs cost benefits. The waterproofing membrane of a normal green roof is almost 10–20 years, and green roof could have life more than 50 years [131]. Bianchini and Hewage [132] used a probabilistic approach to measure the benefits of green roofs and results indicated that the green roofs with correct design are usually economically feasible. Most of the green roof's benefits cannot be counted and it makes it very difficult to analyze the life cycle assessment of green roofs [131]. The rainfall is an important to estimate the cost benefits from the green roofs. For example [133], in Southern European cities the rainfall amount is less so there gives fewer benefits as compared to the Northern Europe (London, Amsterdam and Oslo), where a large amount of rainfall that is good enough for the performance of green roofs (Table 1). Table 1 shows the annual money saving and simple payback period from different European countries.

Previous analysis of the green roofs costs are only considered the construction cost and energy saving costs without counting the many other advantages, i.e. (water management, noise reduction, air pollution reduction and ecological preservation) which are difficult to measure. Therefore, for the life cost analysis, there are factors should consider and measure the benefits of green roofs. Green roofs are proved to be a feasible solution in retrofitting to the existing areas because the old building has less insulation and takes a lot of energy required to cool and warm [37]. Green roofs increase the property values as well as the aesthetic appearance of the building [121,127]. Moreover, lengthen the life of the roof and utilize the surface of the roof or multiple benefits in urban areas [127].

6. Life cycle assessment of green roofs

As a supplement to benefit analysis of green roofs, Life Cycle Assessments (LCA) is to be assumed a suitable approach to better understand the environmental, social, economic and technical aspects. Green roofs have been applied as an environmentally friendly product around the globe and considered as a best management practice. Green roofs showed tremendous results in terms of environmental, economic, and social aspects as compared to the common roof. Bachawati et al. [134] evaluated the life cycle assessment of green roof in Lebanon. Vegetative roof was installed in an urban area of Lebanon. To estimate

Table 1
Annual money saving and simple payback period for different roofing solutions in different European countries with different climatic conditions [133].

	Tenerife		Sevilla		Rome		Amsterdam		London		Oslo	
	Annual saving (€)	Sime payback (year)	Annual saving (€)	Sime payback (year)	Annual saving (€)	Sime payback (year)	Annual saving (€)	Sime payback (year)	Annual saving (€)	Sime payback (year)	Annual saving (€)	Sime payback (year)
Traditional		–	–	–	–	–	–	–	–	–	–	–
Cool roof	2230	8.5	1736	11.4	1494	13.2	373	52.9	410	48.1	310	63.7
Sedum short	− 1296	Negative	− 951	Negative	− 350	Negative	161	488.8	22	> 500	333	236.8
Sedum tall	− 670	Negative	− 267	Negative	− 28	Negative	− 56	Negative	3	> 500	551	143.2
Grass lawn	− 772	Negative	− 163	Negative	− 47	Negative	71	> 500	53	> 500	529	185.5
Short Gramineous	− 594	Negative	− 133	Negative	9	> 500	1	> 500	6	> 500	505	146.4
Tall Gramineous	− 393	Negative	31	> 500	18	> 500	− 363	Negative	− 170	Negative	528	140.1

if the vegetative roofs are better than traditional gravel ballasted roofs and white reflective roofs a cradle-to-gate Life Cycle Assessment (LCA) was performed. Environmental impacts of an existing extensive green roof were compared with other three roofs of same area named as traditional gravel ballasted roofs, white reflective roof and intensive green roof. The main unit used for the comparison of LCA was surface area around 834 m^2 and for 45 years. For the analysis of results SimaPro software and Ecoinvent library were used in this study [134]. Analysis of LCA indicated that the extensive green roof was the suitable choice for environmental impact categories as compared to the others [134]. Similary, Vacek et al. [135] performed the Life Cycle Assessment of four semi intensive green roof assemblies, i.e. common assembly, assembly with added extruded polystyrene and two assemblies with hydrophilic mineral wool. The Life cycle has been analyzed by using a 20 years cradle-to-grave model [135]. The main purpose of this research was to evaluate the environmental impacts of the man made materials (e.g. hydrophilic mineral wool) on green roof assemblies. From the result analysis, it was found that the assembly with the addition of extruded polystyrene and mineral wool in substrate have shown highest environmental impacts over the other assemblies. Results also allows to say that the proper use of the hydrophilic mineral wool enhances the environmental impacts by approximately 11% as compared to the common assembly.

Lisa and Robert [136] investigated the life cycle assessment of both extensive and intensive green roofs versus conventional roofs in Pittsburgh, PA, USA. From the analysis of results, it was found that the green roofs are the environmentally preferable option because they can reduce energy demand of the building and can increase the life of the roofing membrane as compared to the conventional roof. Chenani et al. [137] evaluated the environmental performance of layers of two lightweight green roof systems. The layer materials were analyzed that the water detention, drainage and substrate layers contained the different components that were not environmentally sound. Research results indicated that the rockwool, the plastic drainage layers and expanded clay had the greatest negative environmental impact. The results also suggested that the simple roof systems were more feasible and environmental friendly as compared to the artificial one. Therefore, this study suggested to use the simple materials in green roof layers is very helpful to enhance its environmental performance in urban areas [137].

The research on the green roof construction has shown multiple environmental, social and economical benefits as compared to the common roof [138–142]. Saiz et al. [138] used Life Cycle Assessment (LCA) approach to evaluate the green roof benefits which was applied to an eight story residential building in Madrid, Spain. Bottom-up LCA approach was applied with assuming 50 year building life. Results indicated that the green roof annual energy use reduced over 1%, but in the summer season it reduced over 6% over the common roof [138]. Results also concluded that the green roof environmental impact reduced by between 1.0% and 5.3% as compared to the common roof [138]. Bianchini Hewage [139] performed life cycle net benefit-cost analysis of extensive and intensive roof to check their Net Present Value (NPV) per unit area [6]. A probabilistic analysis was performed to evaluate the personal and social NPV and payback period of green roofs. From the analysis, results that the green roofs are financially sound practices in terms of net returns. The Analysis also showed that there is a low risk in applying green roofs. However, over the life cycle of the green roofs, both personal and social sectors acquire economic benefits [139]. This study also concluded that the green roof construction has multiple benefits (social, environmental and economic) as compared to the common roof. This will not only solve water related problems, but also helps to make cities safe, sustainable and resilient to climate change.

7. Policies applied by different countries for the promotion of green roofs

Due to the multiple environmental, social and economic benefits from the green roofs, the policies are adopting from different countries the application of green roofs [143,144]. These policies usually consist of finical incentives or water or property fee reduction, etc. These policies encourage to the inhabitants for the application of green roofs in urban footprints to achieve multiple environmental benefits.

Various countries introduced the laws for the application of green roofs. In Japan, Tokyo introduced the law for the application of green roofs in private buildings with built areas larger than 1000 m^2 and in public buildings with built areas larger than 250 m^2 [145]. For example, in Darmstadt, the building owner can receive a maximum of € 5000 for a green roof. Similarly, in other cities i.e. Cologne, Mannheim and Bonn, the stormwater fee will be reduced for the user after applying the green roofs. In other countries like Austria and Switzerland, similar policies have been applied for the application of green roofs. In Basal, Switzerland, the owner is repaid 20% of the total cost of the green roof [145]. Table 2. Show the promotional incentive policies for the application of green roofs in different countries.

In Toronto, green roofs should apply with a ratio of 50–70% of the entire building coverage. In Quebec, the money is paid to the user per square meter implemented of green roofs [143,144]. In the USA, most of the states have their own policies for the application of green roofs. For instance, In Portland to reduce the pressure on the sewer system Floor Area Ratio Bonus is introduced to the user. Similar in Nashville is promoting the green roofs with a $10 reduction in a property's sewer fee for every square foot of green roof. In Singapore, a Gross Floor Incentive Scheme for green roofs is introduced that will give financial benefits to the user for the application of green roofs [144]. Followed by the policies of the above countries, several countries like China, Hong Kong, Malaysia and South Korea are also promoting the green roofs adaptation in urban areas. Moreover, they are also trying to make some direct or indirect incentives policies for the users.

Table 2
Promotional policies for the application of green roofs in different countries, modified from [21].

Country	Promotional policies for the application of green roofs
Germany	Munich: green roof must be applied to all flat roofs with surface area > 100 m^2 Esslingen: Users will be compensated 50% of the cost of the green roofs Darmstadt: users receive up to € 5000 for applying green roof
Denmark	Copenhagen: all new roof with roof pitch under 30^0 have to be landscaped, green roof should apply in such buildings
Canada	Toronto: New buildings over 200 sq/m must apply green roofs, and green roof should cover 205 t0 60% of the total roof areas Vancouver, BC: all new commercial and industrial buildings over 5000 (sq.m) must apply green roof, otherwise the owner has to pay the fees
Singapore	Promoting the use of green roofs and there is a Gross Floor Incentive Scheme for the users.
Japan	Tokyo: Installation of a green roof is must on the primary building over 1000 m2 and public building more than 250 m^2. Otherwise, the owner has to pay fine annually.
USA	Chicago, IL: It offers up to 50% of cost or $100,000 for development of green roofs covering 50% or more of a rooftop space Portland, OR: The city offers a Floor Area Ratio bonus in its building code (extra 3 sq/ft per foot of green roof may be constructed without additional permits). Seattle, WA: the city offers a Floor Area Ratio bonus of extra 3 sq/ft per foot of green roof Washington, DC: The District's offers green roof rebate program funds about $5 per sq/ft of green roof New York City, NY: users who will apply green roofs of 50% or more of open roof space can get a one year tax credit of up to $100,000 (or $4.5 per sq/ft) Philadelphia, PA: The state offers a credit against the Business Privilege Tax, of 25% of all costs incurred to construct a green roof up to $100,000 Baltimore, MA: The state offers Stormwater Management Tax Credit is 10% of the cost for the new stormwater management techniques (maximum amount $10,000) Minneapolis, MN: user can get 50% credit in the stormwater fees for applying green roof Nashville, TN: is promoting the installation of green roofs by providing a $10 reduction in a property's sewer fees for every square foot of green roof Austin, TX: Green Roof Density Bonus gives a density bonus of up to 8 sq/ft for 1 sq/ft of green roof

8. Advanced modifications and directions in green roofs

Recently, new alternatives and modification in green roofs boosted the green application in different regions all around the globe. A green blue roof is introduced from Korea. This is a new modified form of green roof that is developed by Korea Institute of Civil engineering and building technology (KICT) researchers to achieve the multiple benefits. The green blue roof is a combination of two words: green and blue where the green means the roof has vegetation/plants and blue means is the roof has storage layer same as the blue roof. This roof has one more extra layer in green roof design that helps to store water in soil layer as well as the storage layer. The main advantage of this roof is that this roof can store more water and avoid flash flooding in urban areas. Fig. 10, shows the green blue roof.

Shafique et al. [146] checked the performance of green roofs to control the runoff in urban areas. From the results, it is indicated that the green blue roof store more water in two layers and the runoff is very small as compared to control roof [146,147]. Therefore, this green roof has the ability to store more water as compared to the blue roof and it can use over the area where the flash flooding is a major concern. Green roof water can use for the domestic purpose, such as toilet flushing, irrigation and washing the surfaces [146,147]. This is because the runoff water quality of green roof water is better as compared to grey water. In this way, runoff from green roof could be utilized and domestic water can be saved.

Hybrid photovoltaic (PV) green roofs is a new direction in the green roof industry, it helps to improve the electrical yield [148]. However, for the optimal results from the PV system surrounding temperature and the sunshine is an important factor and should concern while applying PV green roofs [149]. PV panels help green roof by shading and reducing the sun exposure. Chemisana and Lamnatou [150] investigated the PV- green roofs on the pilot scale in Spain. Results indicated that the efficiency of or PV-gazania and gazania and PV-sedum green roofs increased by 1.29% and 3.33% as compared to PV-gravel roof. Another study from Hong Kong showed that a PV-green roof generates 8.3% more electricity than the stand-alone PV cell on an old building [151]. PV green roof showed promising results in several countries. Therefore, it can be used as the sustainable building practices for the sustainable city. However, more research needs with the different plant species in different locations to check the performance for PV green roofs.

Nowadays, green roofs studied and applied for the food production in many different countries [128]. Every country has their own objectives, i.e. (rainwater harvesting, Disconnect roof drains and direct flows to the vegetated area, Conveyance and stormwater art etc.) for the application of green roofs. Countries where the rainfall is abundant in the summer season, they usually applied green roofs to avoid flash flooding. On the other hand, a country, where the drought conditions the selection of green roofs and its components needs special consideration. There should select such a plant that not required watering and enhance water quality. Some countries are applying green roofs for

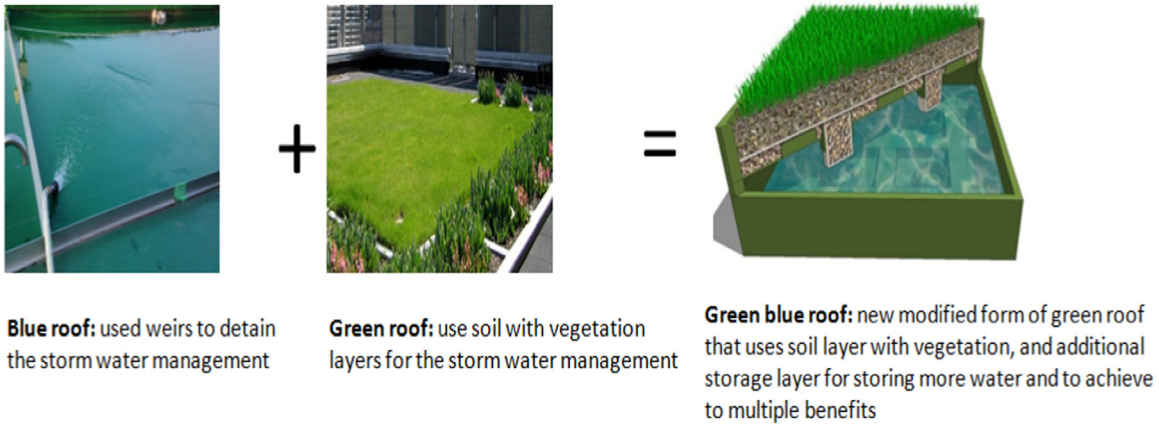

Fig. 10. Green blue roof explanation with other roof types [112].

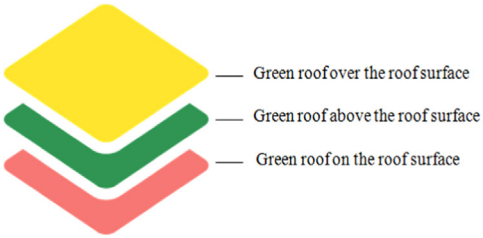

Fig. 11. Multiple Ways to apply green roof on the roof surface.

water quality enhancement and reduction in temperature. Due to continued urbanization, many countries are looking the application green roofs for the irrigation purposes. Green roof components should select based on the following required objective.

- To reduce flash flooding
- To reduce surface temperature (as a result to reduce energy costs)
- For food production
- For the collection of rainwater
- For aesthetic and ecological performance
- To improve the air quality and recreational activities

A green roof is not only means to apply the green vegetation on the roof surface; it can be applied above the surface as well. However, when green roofs applied on the roof surface, then there are some chances that the plant's roots can penetrate into the roof and can cause building structural instability. Green roofs can be applied into following ways. (Fig. 11).

As we know those different locations have different geographical characteristics. Therefore, under these conditions, we can select the optimal position for applying green roof i.e. over the roof surface, on the roof surface or above the roof surface respectively. We should study the site and specifications to find the appropriate place for the application of green roofs. For example, if the plant used in the green roof has longer roots, then it is suitable to apply above the roof surface. On the other hand, if the small roots and we want to improve the water quantity for water utilization then it should apply on the roof surface. The selection of the green roof application place depends on different factors such as the purpose of green roof, the site characteristics, climatic conditions and geographical locations etc. [145,146]. For the best performance it is recommended that the place for the application of green roof is very important and require great concern.

9. Research gap, challenges and technical difficulties

Although green roof is considered as a potential alternative for the pollution control and an effort to retrieve the natural hydrology in urban areas, however, the challenges which limit their use still remain. Even though many research results show that the green roofs are the best management practices due to multiple social, environmental and economical benefits, but many factors such as (high initial cost, unawareness the green roofs construction mechanics and maintenance costs etc.) still hinder the green roofs in underdeveloped countries. Optimal green roof design that can apply to the all locations and weather condition is also the biggest challenges. As most of the researches have done in cold regions, therefore the selection of the green roof plant demands more attentions. On the contrary, in hot regions, there is a need to select the appropriate plant for the better performance of green roof in the summer season. These research challenges and problems associated with green roof research that, we think, all are connected to each other and should be investigated further for the successful implementation of green roofs everywhere.

9.1. Research gap and challenges

The characteristics of green roofs depend on multiple factors, including the initial high construction cost, reduction of use of polymer material and their disposal, high maintenance costs, limited local research, roof leakage problems, and lack of cooperation between different fields. Therefore, it is utmost important to consider all the above factors to solve for multiple benefits of green roofs.

9.1.1. Initial high construction cost

The biggest challenge in the green roof construction is the initial high construction costs. It is usually thought that the green roofs are long term investment (costs) with short term return (Benefits) [81]. Green roof costs depend on the many factors such as location, labor costs, green roof type and material, etc. Bianchini and Hewage [81] reported that the cost of the extensive green roof in British Columbia, Canada deviates from $\$12/ft^2$–$\$15/ft^2$. In contrast, the cost in the other countries such as (USA, Australia, Japan, China, South Korea and India) varies in each country. Niu et al. [18] studies the 1795 m^2 roof area in Washington, DC and reported that installation costs of the green roofs are 27% more than that of traditional roof installation costs. Installation costs and cost benefit analysis of different studies [152,153] showed that green roof is less expansive than the traditional roof.

9.1.2. Limited local research

Green roof research is only limited to few countries such as the USA, Australia, few European and Asian countries, etc. Most of the research has been done in USA and European countries that count almost 66% of total research [33]. Green rood successfully applied in South Korea for roof runoff reduction and surface temperature reduction [146,147,154]. However, in South Korea, the biggest issue is the water quality of green roof is degraded after a period of time. This is because of the use of excess fertilizer in the green roof. Therefore, there is a need to provide the information to every resident for the management of the green roof to achieve the multiple benefits [15,155]. Due to very limited research in under developing countries, the building's owners and stakeholders are not aware of the green roof benefits. There is a need to share information of the benefits of the green roof to the building's owners and stakeholders and encourage them for the application of green roofs.

9.1.3. High maintenance costs

Green roofs require regular maintenance for long term life. However, the research on the green roof maintenance is very limited [119]. It is often believed that the green roofs do not require regular irrigation or fertilizer however, for the optimum benefits from the green roofs in drought conditions, it requires watering and fertilization. Green roofs also require proper maintenance during the different time interval. There should be a regular check on the plant, drainage and substrate of the green roof to extend the life of the green roof.

9.1.4. Roof leakage problems

The green roof should be properly placed to avoid the chances of leakage and structural failure of the buildings. It is believed that the green roofs enhance the roof life double time as compared to the traditional roof [46]. However, if the green roof is not properly placed on the roof, then the chances of the roof leakage and structural building failure becomes high. Therefore, there should be properly studied about different components of green roofs (their weight and storage capacity) to avoid the leakage and other problems in buildings.

9.1.5. Reduction of use of polymer material and their disposal

Most of the green roof components are usually made of polymer materials. However, while the construction of these polymers martial causing pollution. Bianchini and Hewage [81] indicated that the drainage and filter layers of the green roofs are fabricated with 40%

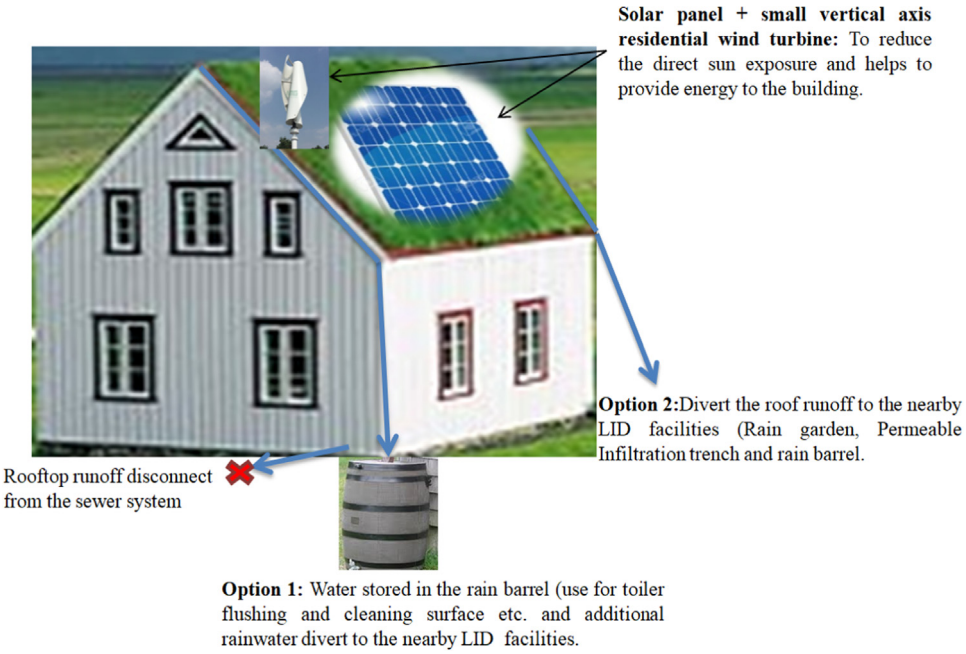

Fig. 12. Potential application of green roof in urban area.

recycled polypropylene. This causes pollution while constructing these polymer materials. There is a more research need to find the appropriate material that can replace these polymer materials and can enhance the green roof performance over a long period of time. On the other hand, deposal of these green roof components should require environmental as well as cost concern. The plastic that used for the green roof cause few problems, as it can be incinerated. There is a need to use the green roof components that can be reused and cause no pollution problems.

9.1.6. Lack of co-operation and collaboration between different fields

The biggest challenge that arises after the construction of the green roof is the management of the system. This is due to the lack of co-operation and collaboration between different fields (architectural, Civil, Environmental engineers and residents). Everyone is finding the answer, who will take care green roofs? If the green roof systems did not monitor or maintain regularly, that causes the loss of all investments. This issue has arisen in the whole world after the construction of green roofs. Therefore, the people should sit on the table and divide their tasks for the management (Construction costs, maintenance costs) of the green roofs. There also needs to co-operate and collaborate between architectural, Civil, Environmental engineers in the application of green roofs in urban areas.

9.2. Technical difficulties

The main technical difficulties regarding the application of green roofs, which is needed to further consideration, are listed below.

- It is very hard to estimate the air quality and ecological improvement, temperature and noise reduction costs for the life cycle cost analysis of green roofs, so it is needed to carry out more research regarding the life cycle cost analysis including the above benefits.
- More work is required to find a more efficient local substrate for the green roof, which can reduce the water quality problems from green roof runoff
- Air, water quality and thermal performance of the green roofs should be advertised to attract the stakeholders and building owners for the application of green roofs.
- Polymer materials that are used in green roof components should eliminate and find the Eco friendly that can enhance the environment.
- A huger effort need for the co-operation and collaboration between different fields for the application and management of green roofs.

10. Potential applications and future prospective of green roofs

This review paper shows that the green roofs are the potential practices to reduce the adverse Effects of urbanization. Green roofs are the best management practices (BMPs) due to multiple benefits such as stormwater management, water quality and thermal enhancement in urban areas. Several research findings show that green roofs can easily integrate into existing buildings and can provide multiple benefits (environmental and social). Green roofs are the potential solutions to protect the natural hydrology as well as the environment of an area. Moreover, it also helps to stop the global warming of an area by reducing the heat waves and improving the climatic conditions.

However, there is a knowledge gap between underdeveloped and developed countries where a lot of research on green roofs already done. More research has done in cold climates areas i.e. (USA, Sweden, Germany etc.) whereas more research needs to be done in different climatic as well as geographical areas. Green roofs components such as vegetation and substrate should select locally to enhance green performance as well as to reduce the green roof costs. More research needs for the life cycle costs and cost benefit analysis of green roofs in different countries. There should be some incentive for the building owners for the application of green roofs; this will lead the adaptation of green roof on a large scale. Stakeholders should encourage the application of green roofs by providing them with some incentives.

As we know that the green roof runoff water quality is better than the traditional roof runoff, so we should utilize this runoff for the optimal purpose such as toilet flushing, cleaning surfaces and irrigating to nearby plants. Fig. 12 shows the proposed green roof application with other possible sustainable practices in urban areas to achive multiple benefits. For example, on the rooftop green roof could connect with solar panel and small wind turbine to achive multiple benefits in urban areas as illustrated in above Fig. 12. This review shows the current research on green roofs from different countries. More research needs in the selection of best combinations of green roofs to nearby Low impact development (LID) facilities. There is also need to connect all LID

facilities (rain garden, green roofs, storage tanks and permeable pavements etc.) to the 4th industrial resolution (IOT) so that the information can get more easily as well as reduce the labor costs. Nevertheless, more research needs for to co-operate and collaborate between different fields (architectural, Civil, Environmental engineers) for the application, management and maintenance of green roofs. Lastly, more research and work required to make green roofs cost effective in every geographical location around the globe.

11. Conclusion

Research work on the green roofs has been challenging and provides a great room of opportunities for the researchers for future research. This paper reviews literature regarding green roof properties, environmental, social and economic benefits, challenges, opportunities and potential applications of green roofs. Although significant features have been reported, however there are many facts such as high construction costs and management problems should also be considered for the potential applications around the globe. In this review paper, an effort was made to demonstrate how green roof can help mimic the natural hydrology as well as stop global warming of an area. There is also need to develop a more cost effective green roof practices for the multiple benefits (environmental, social etc.). Nevertheless, more in-depth real experimental work on the each component of the green roof is required, and multidisciplinary research collaboration in dealing the challenges is imminent. Lastly, cost effective design of the green roofs, there are a lot of challenges and opportunities in the future to come.

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